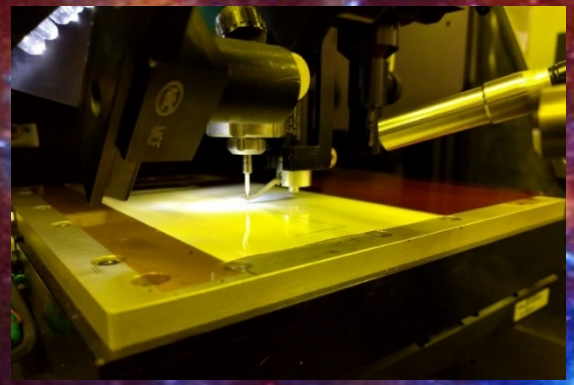
Aerosol Jet Printing on Rigid and Flexible Substrates for Space Applications



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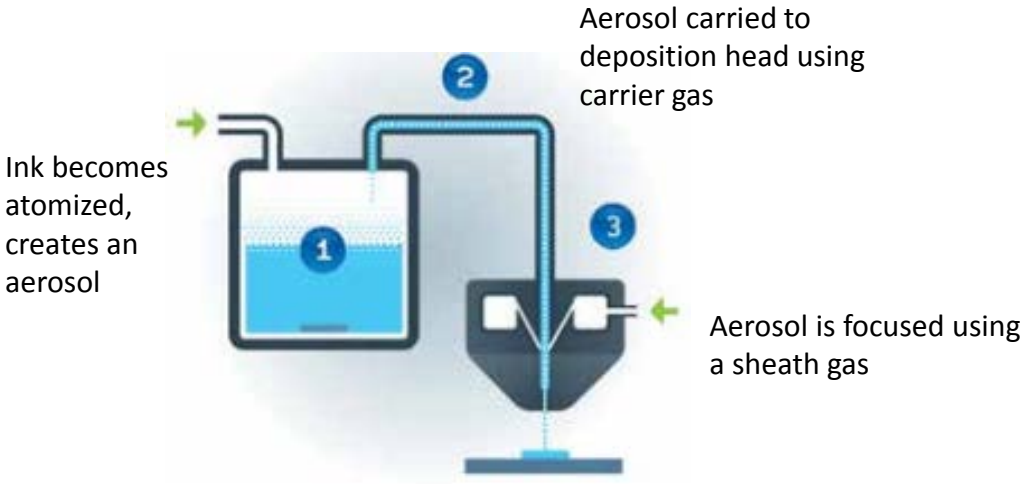
Nextflex Workshop: FHE Applications for Aerospace
April 1-4, 2019

Introduction: Direct-Write Printing and Aerosol Jet Printing

- Direct-Write Printing – additive manufacturing technique where electronic components and circuits are fabricated by depositing materials onto a substrate without the use of masking or etching
- Aerosol Jet Printing is a type of direct-write printing that uses aerodynamic focusing to precisely and accurately deposit nanoparticle inks onto substrates[1]

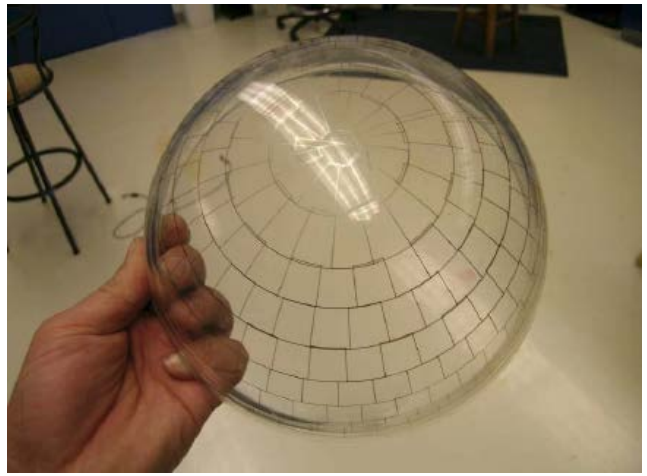


http://www.optomec.com/

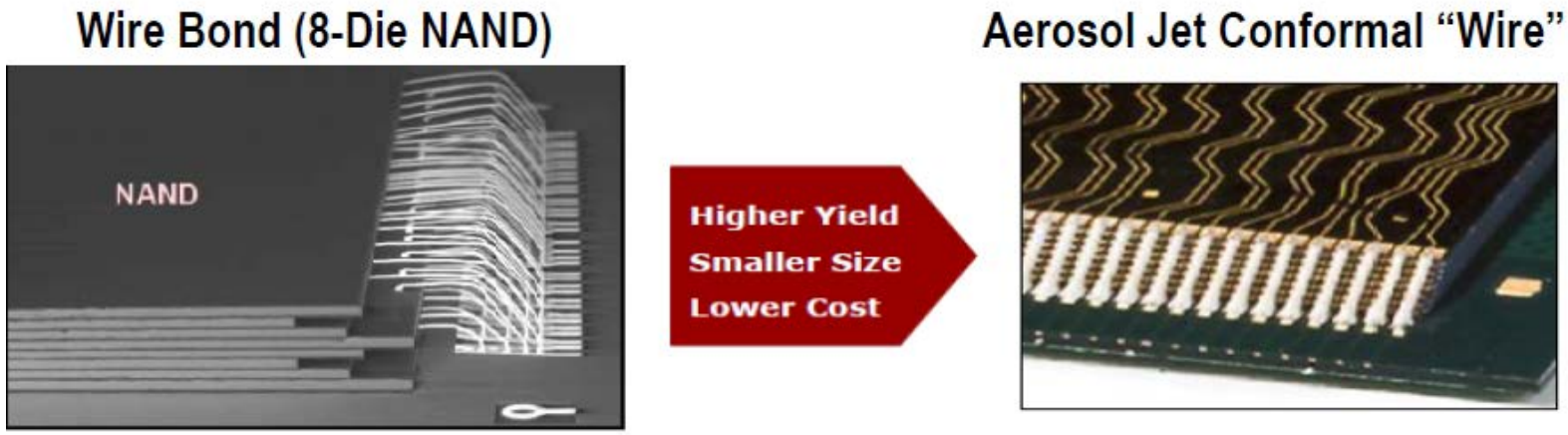
1. Optomec http://www.optomec.com/printed-electronics/aerosol-jet-technology/

Why Aerosol Jet Printing?

- Feature sizes down to 10 microns
- Variety of substrates – flexible, rigid, 3-dimensional non-planar

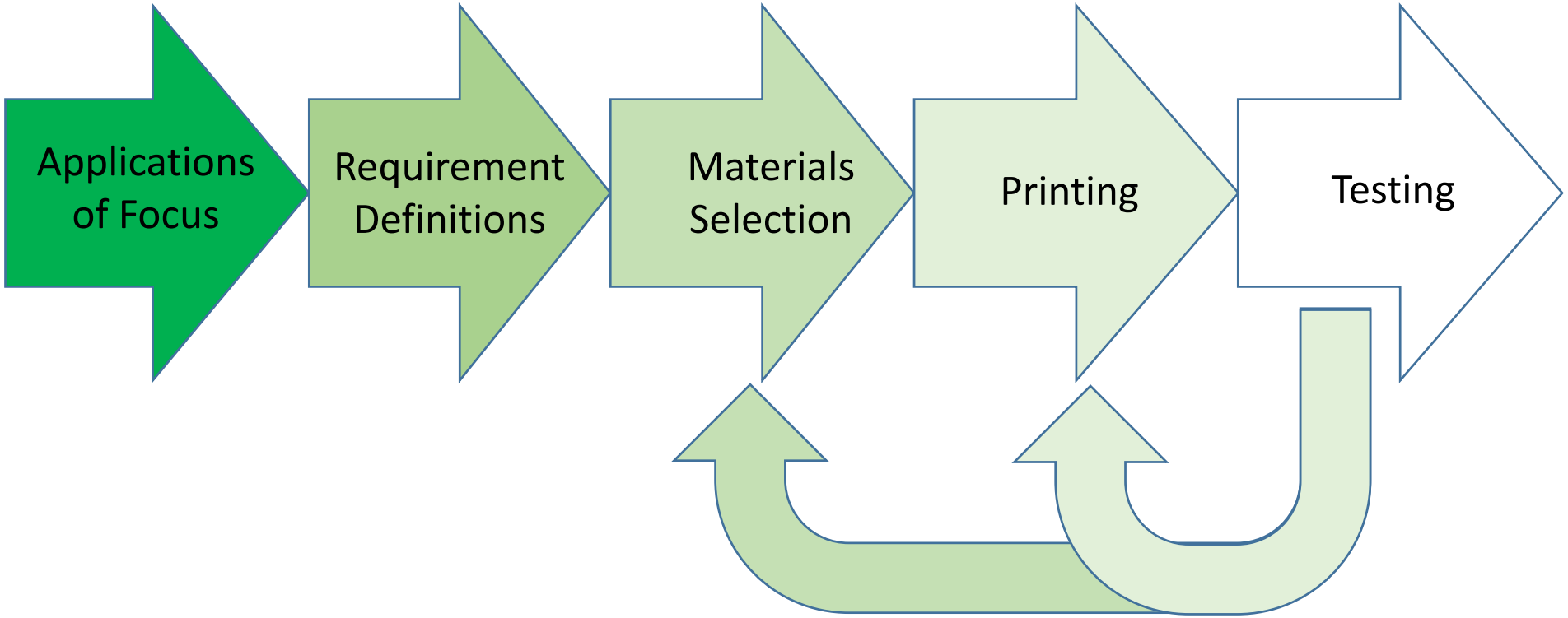


EMI shield (Optomec)



Aerosol Jet Printed Interconnects vs wire bonds (Optomec)

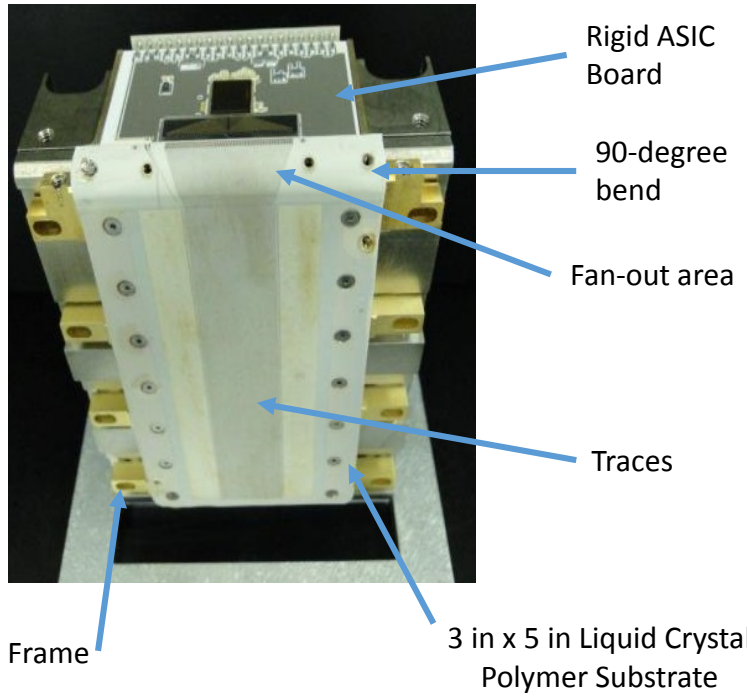
Research Method



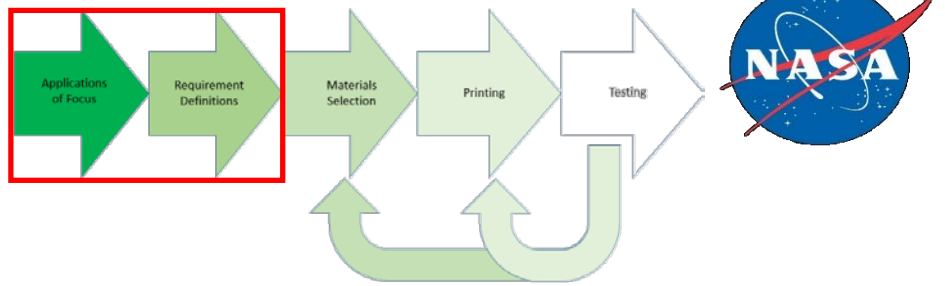
Next Generation X-Ray Polarimeter (NGXP)

- Study sources of X-Rays such as black holes, pulsars, supernova remnants
- Photoelectron tracks are imaged using strip detectors in a gas environment
- Original strip design: traces at 121-micron pitch, etched into copper cladding on a liquid crystal polymer substrate
- The minimum pitch of the strips and the area required to fan the strips in to the pitch of the ASIC readout is limited by the accuracy of the etching, and limits the gas choices and pressure, thus restricting the achievable sensitivity
- Reducing the pitch could reduce the Polarimeter design in size, which saves mass, and improves track resolution
- **A reduction in strip pitch will enable the detector sensitivity to be increased by more than a factor of three and a mission sensitivity increase by more than a factor of ten**

Assembled Strip Detector

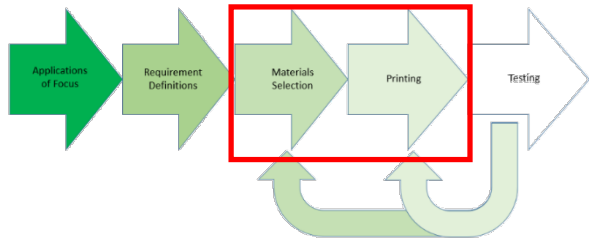


NXGP Requirements

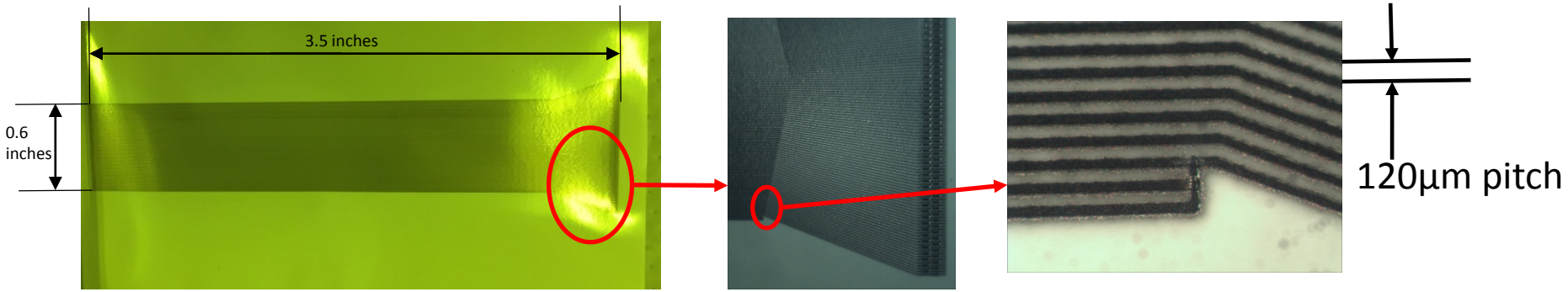


- Application: Strip Detector for Next Generation X-Ray Polarimeter
- Mechanical:
  - Printed traces:
    - At maximum, 60 micron width traces with 121 micron pitch
    - Bend around a 90-degree corner of ¼-inch radius
    - Survive being pulled flat
  - Substrate:
    - Low moisture absorption rates: .04%/24 hours
    - Has a high melting temperature: 250˚C minimum
    - Has a high surface resistivity: 10^{12} Mega ohms
- Environment:
  - Outgassing:
    - Total mass loss <=1%
    - Collected Volatile Condensable Material <=0.1%
  - Temperatures:
    - 125˚C for 10 days
    - +20˚C to +30˚C operational
    - 10˚C to 40˚C survival
  - Vibration, shock and acoustics per NASA Goddard's General Environmental Verification Standard GSFC-STD-7000
- Electrical:
  - Low capacitance
  - Carry 1-microamp pulses, 500 pulses per second

NGXP Flexible Prints

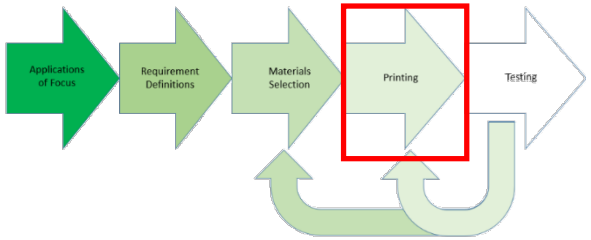


- Materials:
  - Gold and silver inks
  - Kapton and Liquid Crystal Polymer (LCP) Substrates
- Printer:
  - AJ200
  - Pneumatic atomizer for silver ink
  - Ultrasonic atomizer for gold ink

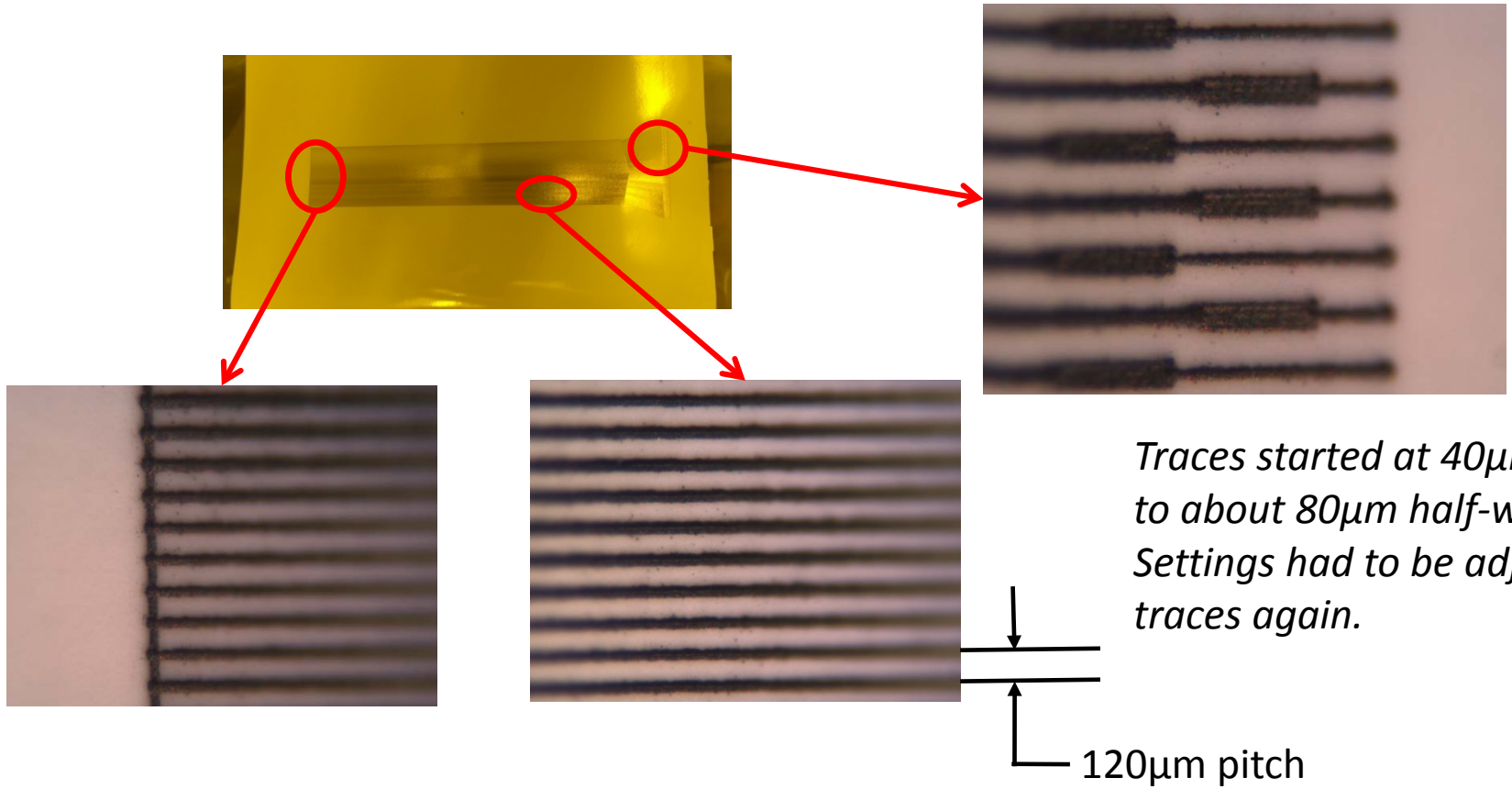


Silver printed on Liquid Crystal Polymer with pneumatic atomizer. 200µm tip used. Traces 60-80µm throughout print.

NGXP Flexible Prints

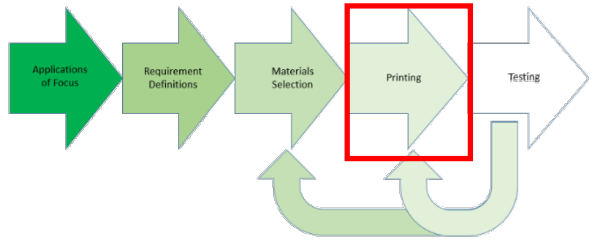


Silver printed on Liquid Crystal Polymer with pneumatic atomizer. 100µm tip used.

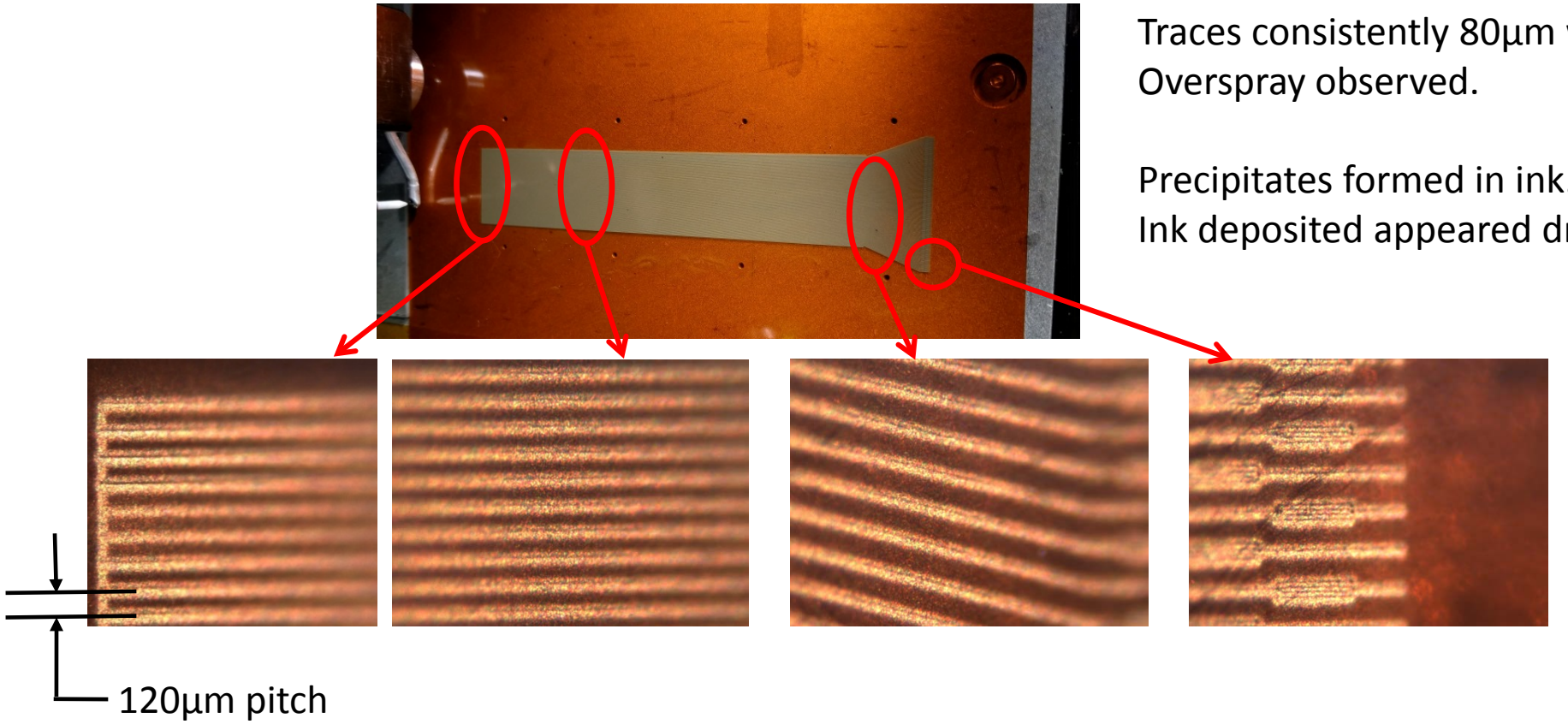


Traces started at 40µm width but got wider to about 80µm half-way through printing. Settings had to be adjusted to get thinner traces again.

NGXP Flexible Prints



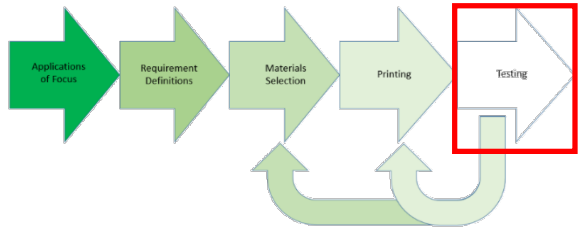
Gold printed on Kapton with ultrasonic atomizer. 200µm tip used.



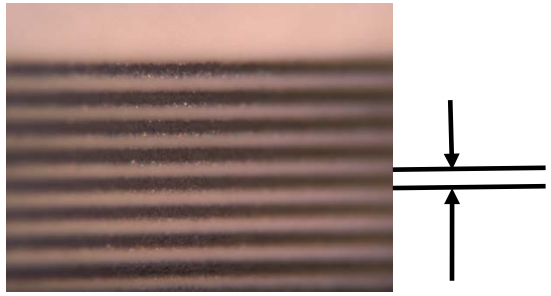
Traces consistently 80µm wide.
Overspray observed.

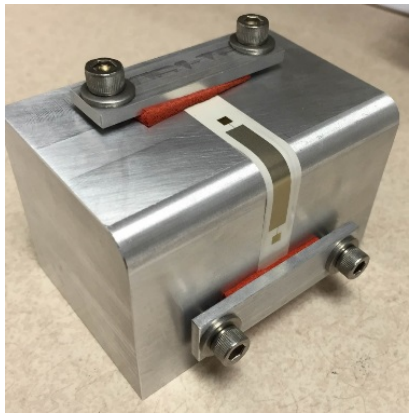
Precipitates formed in ink.
Ink deposited appeared dry, powdery.

NGXP Flex Mechanical Tests

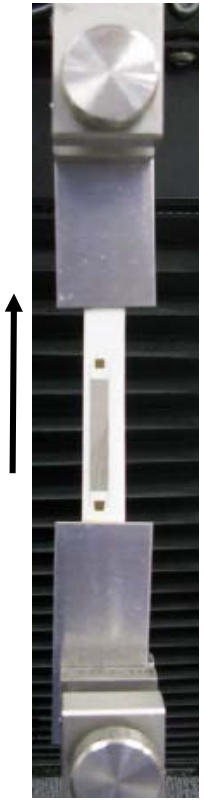


Visual Inspections, Measurements



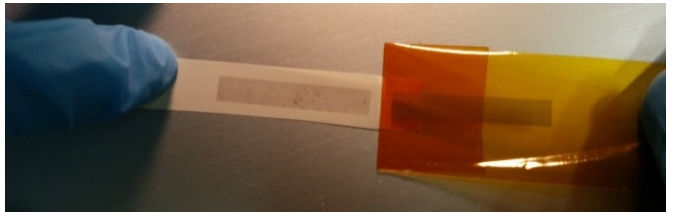


Bend Testing



Tensile Testing

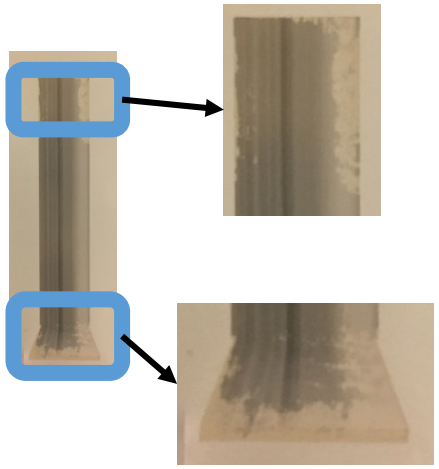
Tape Testing



Tape pull direction

Tape pull direction

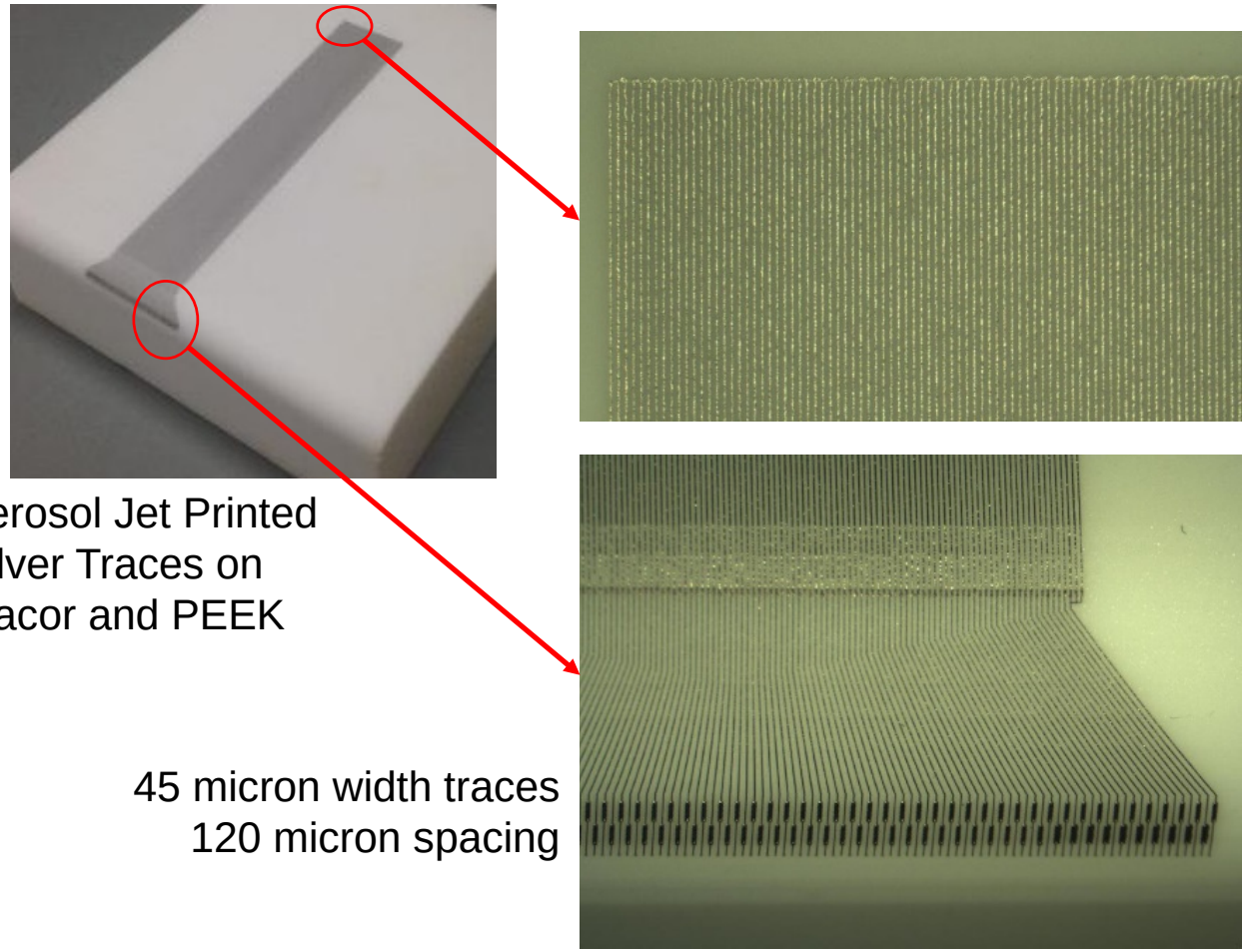
After Pull:



Observations:

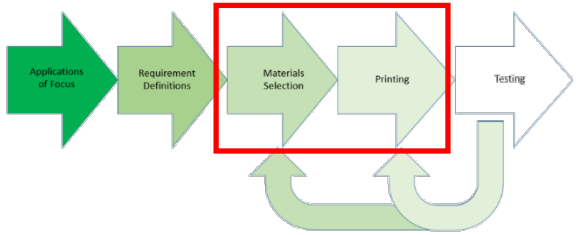
- Inks seem to behave differently over time
- Printing parameters need to be adjusted over length of print
- Results vary between printer operators
- Gold ink more cumbersome to use, store, care for
- Adhesion of silver inks to LCP needs improvement

NGXP Rigid Prints

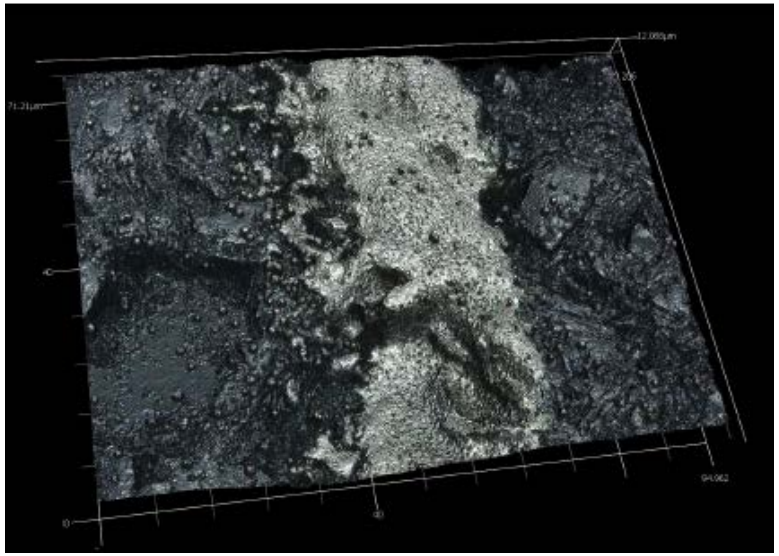


Aerosol Jet Printed
Silver Traces on
Macor and PEEK

45 micron width traces
120 micron spacing

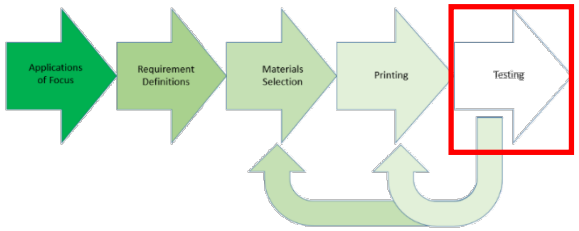


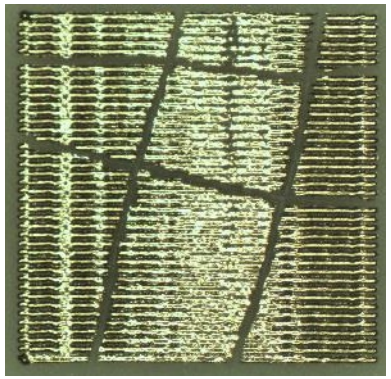
Visual and topography imaging



Traces measured 45.5µm+/-4.4µm

NGXP Rigid Print Tests

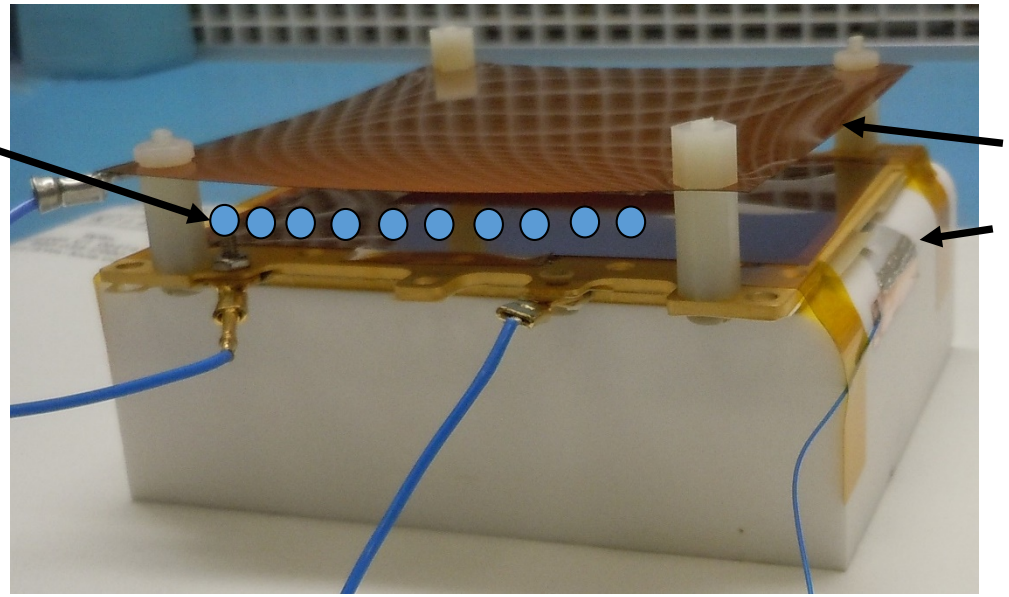




ASTM Adhesion Tape Test
Class 5B and 4B observed
5B – no film pull-off
4B – small flakes only

Printed Detector Strip in X-Ray Test Fixture

X-Rays move perpendicular to traces

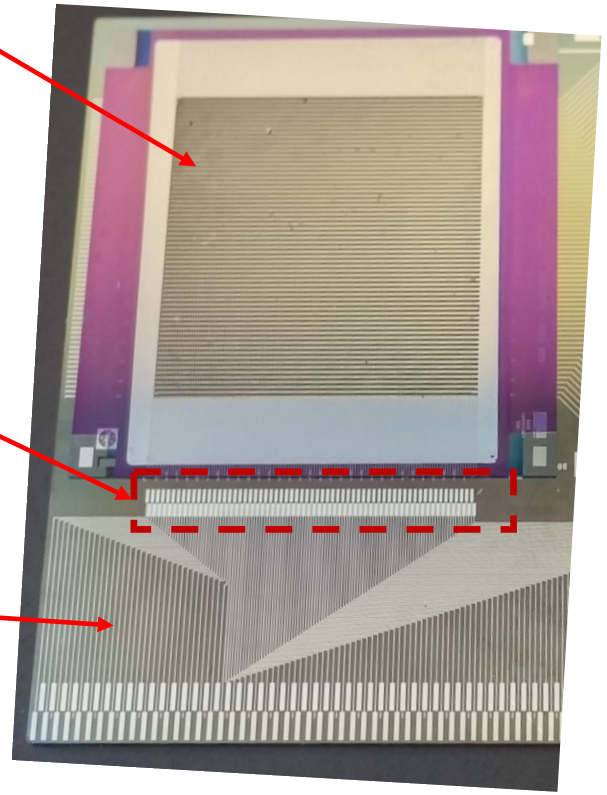


Electrode layer

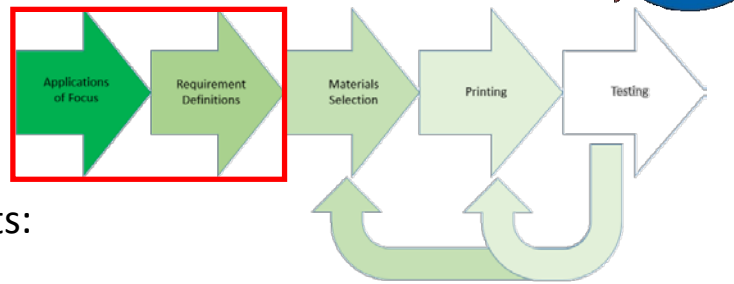
Printed Strip

Strip survived 16 hours of X-Ray testing. No damage to traces observed.

Next Generation Microshutter Arrays (MSA)

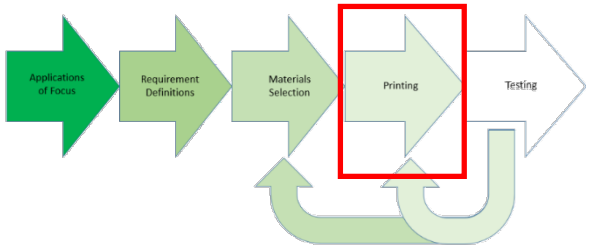


Microshutters select many objects in one viewing for simultaneous observation – High-resolution spectroscopy



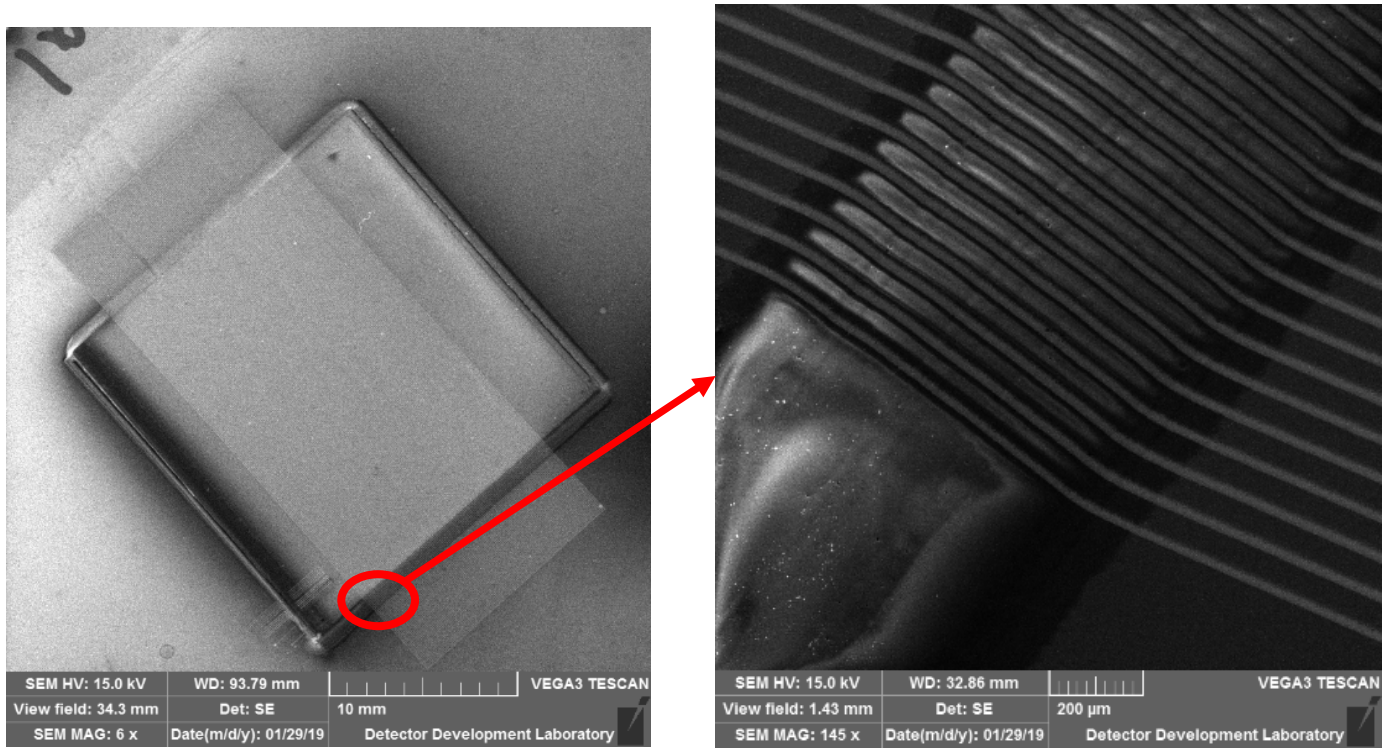
- Mechanical Requirements:
  - Printed traces:
    - At maximum, 20 micron width traces with 100 micron pitch
    - Interconnects to be printed from substrate pads to top of MSA pads
- Environmental Requirements:
  - Outgassing:
    - Total mass loss <=1%
    - Collected Volatile Condensable Material <=0.1%
  - Temperatures:
    - Bakeout: 100˚C
    - Assembly: 75˚C
    - +20˚C to +30˚C operational
    - 10˚C to 40˚C survival
  - Vibration, shock and acoustics per NASA Goddard's General Environmental Verification Standard GSFC-STD-7000
- Electrical Requirement: Resistance: ≤500Ω per individual interconnect

MSA Printed Test Samples



Printed Sample on Silicon Squares attached to Wafer

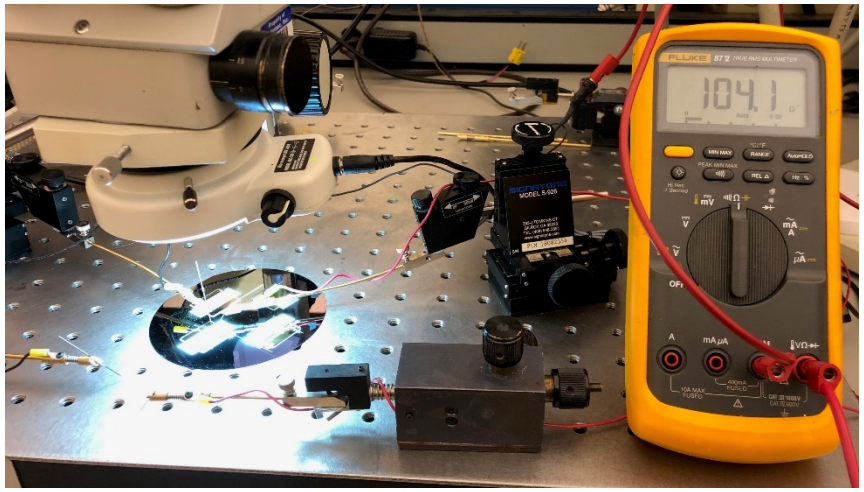
Printed silver lines with 20um width over insulating fillet/"ramp"

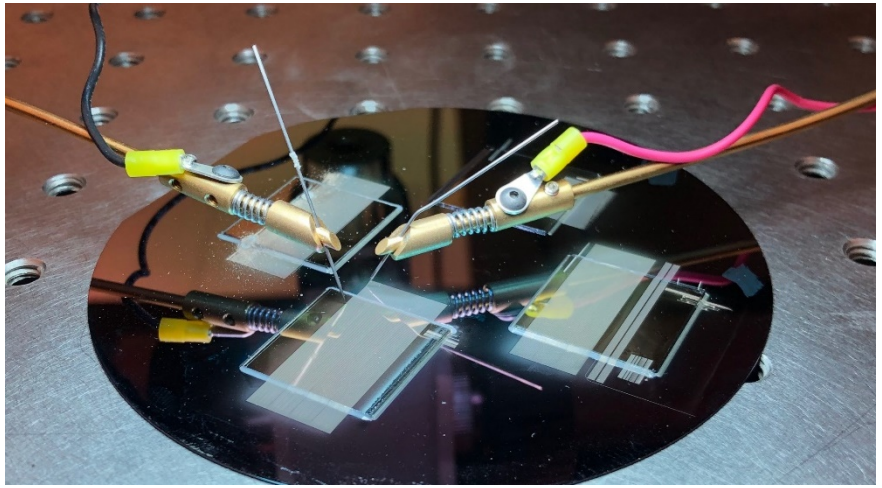


Scanning Electron Microscope Images of printed interconnects by GSFC

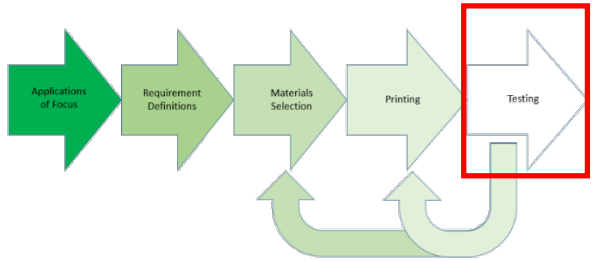
- Insulating Fillet:
  - Syringe Deposit and Print
- Conductive Traces:
  - Silver ink
  - Sinter Method 1: Laser
  - Sinter Method 2: oven cure

MSA Sample Tests





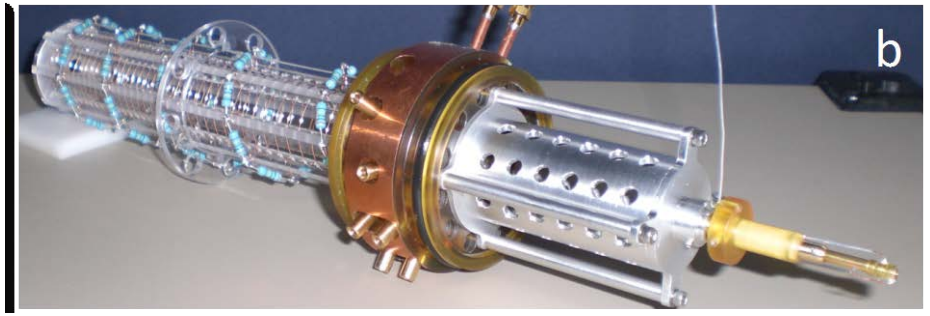
Probe setup (Optomec)



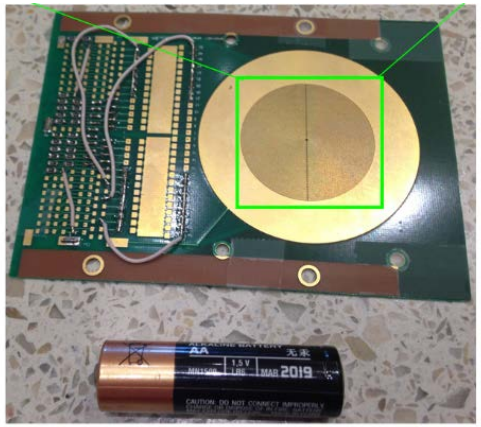
- Probed Test samples:
  - *Difficult to probe because traces are so small!*
  - **Resistance measured across conductive traces: 12Ω**
  - Between traces:
    - Resistance on order of MΩ, but needs to be on order of GΩ
    - Trying plasma treatment to increase resistance
    - Printing a second set of interconnects on a new wafer

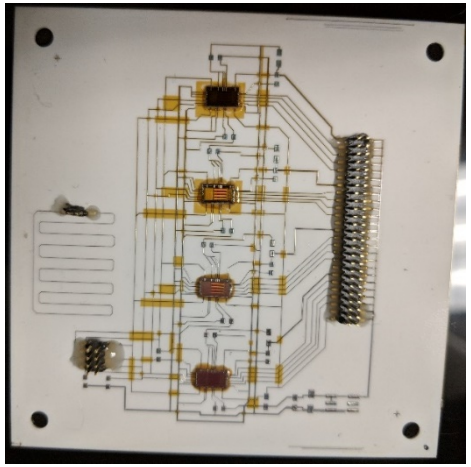
Future Work

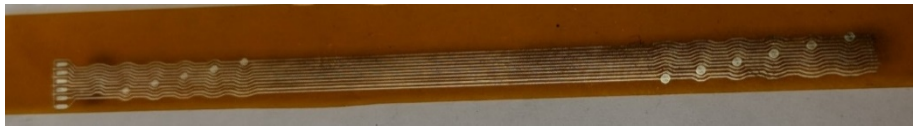
- Continue Testing of MSA and NGXP Prints, and record lessons learned for next iteration of design
- Integrate ASIC board design into NGXP assembly
- Additional potential applications:
  - Magnetometer bobbin wires
  - CubeSat circuits
  - Variety of flexcircuit and printed interconnect applications, including MicroWell Detector Tiles
  - Mass spectrometer applications, including ion funnels and reflectron tube electrodes



Reflectron Tube Electrodes, Courtesy T. Cornish


Ion Carpets, Ion Funnels, Courtesy H. Wollnik


Printed Interconnects


Flexcircuits

Special Thanks:

- Goddard Space Flight Center
  - Parts, Packaging and Assembly Branch
  - Peng Chen
  - Kevin Black
  - Joe Hill
  - Justin Jones
  - Cameron Parvini
  - Wes Powell
  - Margaret Samuels
  - William Brinckerhoff
- Furman Thompson, Marshall Space Flight Center
- Dan Hines, Laboratory for Physical Sciences
- Mike Renn, Optomec

Questions?

Contact:

beth.m.paquette@nasa.gov

Acronyms

Acronym	Definition
ASIC	Application Specific Integrated Circuit
LCP	Liquid Crystal Polymer
MSA	Microshutter Array
NGXP	Next Generation X-Ray Polarimeter
PEEK	Polyetheretherketone